FIGS. **6** and **7** are diagrams of example coating configurations within the evaporative region of an electronic circuit package cooling system according to some implementations.

FIG. **8** is a diagram of an example coating configuration within the condensing region of an electronic circuit package cooling system according to some implementations.

DETAILED DESCRIPTION

Heat dissipation is a major concern for manufacturers of electronic circuit packages, such as an integrated circuit die package. As manufacturers create electronic circuit packages (ECPs) with greater computing and processing capabilities, the need for improved cooling solutions also increases in order for users to gain the full benefit of these high-performance electronic circuit designs without being hindered by performance degradations due to sub-optimal management of heat that is generated by the more powerful ECP. Heat pipes and vapor chambers have often been used in this domain to cool ECPs. Typically, in legacy solutions, as ECP power increases, the cooling performance declines because the solutions are unable to dissipate enough heat at a fast enough rate to ensure optimal performance of the ECP. Often the cooling capacity of a particular heat pipe or vapor chamber design does not match the heat generation profile of a given ECP for which the cooling solution has been applied. As a result, temperatures in the ECP rise which can degrade ECP performance and/or negatively impact the life-span and reliability of the ECP. Cooling solutions that include liquid cooling methods are available but often involve increased cost and design complexity. The cooling systems disclosed herein can avoid the expensive design, manufacturing, and maintenance requirements that are typically associated with liquid cooling solutions. The disclosed cooling systems are also well-suited for deployment with high-power components (e.g., processors performing computationally intensive operations, such as machine learning applications) and may enable use of higher processor speeds to increase chip performance.

The disclosed cooling systems include a number of features to improve heat transfer away from an ECP to which the cooling system is attached. These features, alone and/or in combination, can help enable the evaporation process to be improved, and in some cases optimized, for a particular heat source, resulting in more efficient and consistent heat transfer away from high power density ECPs. The disclosed cooling systems may include a single continuous liquid-vapor chamber. The chamber may include an evaporator plate, which is in contact with the ECP and transfers heat into a liquid coolant that is included in the chamber. The liquid coolant may then evaporate as heat is absorbed from the ECP and the moisture vapor generated from the evaporating liquid may accumulate in the condensing tubes. In the condensing tubes, the heat contained in the moisture vapor may be transferred to the condensing tube walls and consequently to an external cooling medium (which may include water or air, or other fluids). The liquid condensate that accumulates on the inner surface of the condensing tube walls may then flow back to the evaporative region from the condensing tubes. The cooling system can include independent structures, referred to herein as spacers that fluidically couple the condensing tubes to the evaporative region. Such spacers may include a rigid component and/or a wick, to provide a continuous flow of liquid coolant for more efficient heat transfer. The spacer may act as a "bridge" between the end of the condensing tubes closest to the evaporator plate (referred to as the "proximal end") and the heat transfer plate

of the evaporative portion of the chamber. The wicks may provide a wicking effect, drawing the condensate liquid from the condensing tubes back down into the evaporative portion of the chamber, rather than allowing the liquid to accumulate in the proximal end of the condensing tubes and drip down into the evaporator plate.

As an additional feature, the inner walls of the evaporative portion of the chamber may include surface coatings to improve evaporation efficiency. For example, a copper powder may coat the heat transfer plate and the surfaces of the chamber that are opposite the heat transfer plate. In some implementations, the surface coating may also coat the walls of the chamber and/or the inner walls of the condensing tubes. In some implementations, the inner walls of the condensing tubes lack a surface coating, and instead include a series of longitudinal grooves that extend the length of the condensing tubes.

In some implementations, the wick may include a multi-layer copper mesh extending between the condensing tubes and the heat transfer plate. In addition, fins may also be added to the internal surface of the heat transfer plate to increase the surface area of the heat transfer plate. The fins may also be coated with a copper coating to boost the evaporative efficiency of the cooling system.

The heat transfer plate may be attached to an upper portion of the chamber to form an enclosed, single-volume, continuous liquid-vapor cooling system. The condensing tubes may be connected to the sides of this enclosed chamber or to the top (or a combination of both connection configurations). As described above, the condensing tubes may include a wick to provide a capillary effect and improve fluid circulation between the evaporative and condensing regions of the chamber. Alternatively or in addition, the condensing tubes may include grooves to reduce the friction of the condensate on the condensing tube inner walls and may facilitate movement of the condensate back to the evaporative region.

The disclosed cooling system architecture enhances the air cooling capacity of the condensing tubes and addresses the problem of managing high heat flux that is typically generated by high power ASICs or microprocessors. Often, the configuration of high power processors included in an ECP can greatly affect the heat transfer performance of the cooling system used to cool the ECP. A solution to this problem may include a cooling system that is optimized for the configuration or layout of the high-performance components that are included in a particular ECP configuration. For example, an ECP configuration may be arranged such that numerous microprocessors are positioned around the perimeter of the ECP. A cooling system that includes design elements in the center of the ECP may not demonstrate the same heat transfer capabilities as a cooling system configured with heat transfer features that are similarly mapped or positioned in relation to the heat generating components of the ECP, such as cooling system features that are configured around the perimeter of the cooling system in positions corresponding to the heat generating processors of the ECP. One way the disclosed cooling systems disclosed herein address this problem is by enabling an ECP manufacturer to customize the shape, elevation and density of a plurality of fins that may be arranged on the heat transfer plate that is coupled to the ECP. The fins may be arranged in a uniform pattern or an irregular pattern that is designed to optimize the heat transfer away from the heat generating portions of the ECP over which the fins are located. In the disclosed cooling system, regions of the ECP with a greater density of heat-generating ASICs or microprocessors may be mapped and a